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Status and outlook of China's free-carbon electricity

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ABSTRACT

Global warming, increased energy demand, and tremendous air pollution are forcing China to revise its energy structure of electricity generation dominated by coal (80% of total electricity) towards low-carbon electricity. Vigorous development of carbon-free energy resources of electricity is a practical way towards low-carbon electricity in China. In this paper, we shall outline renewable power generation (hydropower, wind power, solar energy, biomass energy, nuclear power, ocean energy and geothermal) together with nuclear power for China, present a reserves assessment, the current status, and barriers for further development, and finish with an outlook towards the future. In our view, China has plenty of free-carbon energy resources to revolutionize its electricity structure and redirect it towards low-carbon electricity systems. Needed are the effective energy policies to get to the way.

Contents

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1. Introduction

In recent years, the electric power industry of China has witnessed a high-speed growth. The total installed capacity has above doubled since 2003–2008, from 380 GW (gigawatt) to 793 GW [1,2]. In 2006 alone, 102 GW of new generating capacity was added, an increment substantially larger than the United Kingdom's entire electric power system [3]. China's installed capacity of electric power is projected to reach or exceed 900 GW by 2010, and is likely to become the largest electric power system in the world in 5 years or so [4].

Of the installed capacity of 793 GW in 2008, the installed capacity of coal-fired power amounted to 601 GW [1]. Meanwhile, renewable electricity and nuclear power are underdeveloped. In consumption of primary energy, the percentage of hydropower and nuclear power in China is 5 points lower than the world's average, whereas the percentage of coal 41 points higher [4].

However, coal consumption has been the main cause of smoke pollution in China, as well as the main source of greenhouse gas [5]. Increasingly environmental and ecological pressure has been caused by the consumption of coal. Acid rain as a result of excessive coal production is almost constant in one-third of China's territory [4,6]. Of course, the biggest problem is CO_2 emission. In 2006, coal combustion accounted for 82% of China's CO_2 emissions [7,8].

These facts and numbers mentioned above clearly indicate that much remains to be done to develop the carbon-free electricity (renewable electricity and nuclear power). This includes fresh thinking about the energy pricing system [9], and in some cases new technologies [4]; it also means new transmission systems and smarter grids [10]. Above all, the various sources of carbon-free generation need to be scaled up to power an increasing demand. In this paper, we shall outline renewable power generation (hydropower, wind power, solar energy, biomass energy, nuclear power, ocean energy and geothermal) together with nuclear power for China, present a reserves assessment, the current status, and barriers for further development, and finish with an outlook towards the future, in order to look at how much carbon-free energy might ultimately be available—and which sources make most sense in China.

2. General background of China's power

2.1. General information concerning China's power installed capacity

China's first power generation with an installed capacity of 11.67 kW machine was launched in 1882 in Shanghai. China had built a total generation capacity of merely 1.85 GW nation-wide [11] during the first 70 years from the launching of the first commercial power generator to the founding of the P.R. China in 1949. Power generation capacity has been expanding at an accelerated speed, especially since the late 1970s when the "reform and open-door policy" started (see Fig. 1). It took almost 30 years, from 1949 to 1978, for China to increase its total capacity to 57 GW. In contrast, the annual addition of generation capacity increased from a few GW in the 1980s to 10–20 GW in the 1990s [11] to almost 100 GW in later years [4]. The total installed capacity has above doubled since 2003–2008, from 380 GW to 793 GW [1].

China's energy sources and sinks tend to suffer from geographical mismatch between supply and demand, coal being concentrated in the North and Northwestern, hydro concentrated in the Southwest, and only nuclear energy being concentrated in the high usage area as shown in Fig. 2.

Construction and development of power grids in China tend to be sluggish. The seven individual grid systems function well but

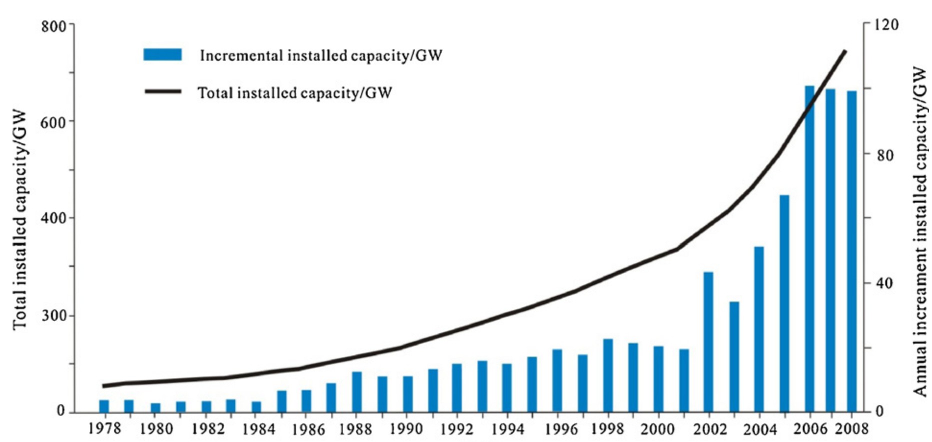

Fig. 1. China's power installed capacity/GW. *Source*: [1,2].

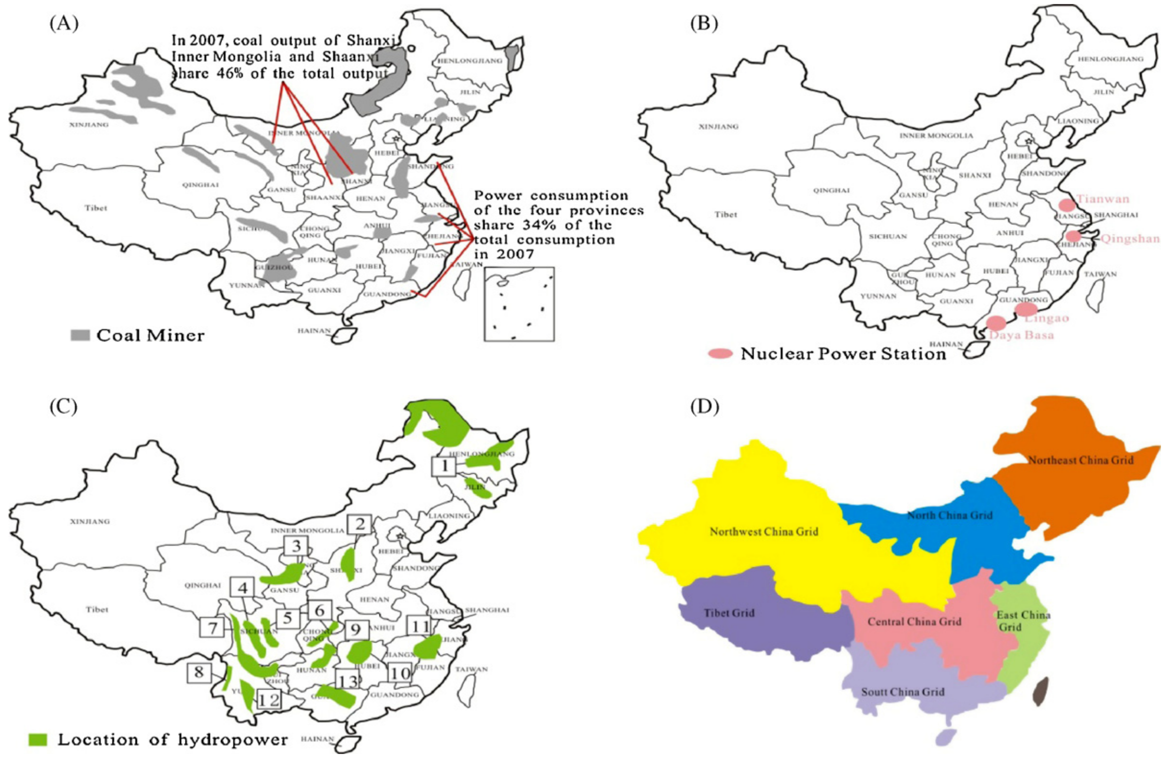

Fig. 2. (A) The location of coal miner and main power consumption; (B) the location of nuclear power; (C) the location of hydropower basis and (D) China's seven individual grid systems.*Source*: [12,14,15].

their interconnections not, resulting in an insufficient inter-grid electricity exchange capacity (see Fig. 2). From 2002 to 2007, investment in generation capacity increased from RMB 74.7 billion Yuan (US$ 9.0 billion) to RMB 322.6 billion Yuan (US$ 42.2 billion) at an average annually increase of 28%. At the same time, investment in grids increased at an annually at only 9%, from RMB 157.8 billion Yuan (US$ 19.0 billion) to RMB 245.1 billion Yuan (US$ 32.3 billion) [12]. China lacks a unified power grid network across the nation and plans to set one up by 2020 [13].

2.2. China's power addiction to coal

No other nation depends on coal to the extent that China does (see Fig. 3). Coal accounts for 70.4% of China's energy use, compared to 28.6% for the world average in 2007 [16]. From 2000 to 2007, China's annual raw coal output has increased by nearly 1226 million tons, reaching 2525 million tons in 2007 [15]. The output of China's coal accounts for approximately 41% of the world total in 2007 [16].

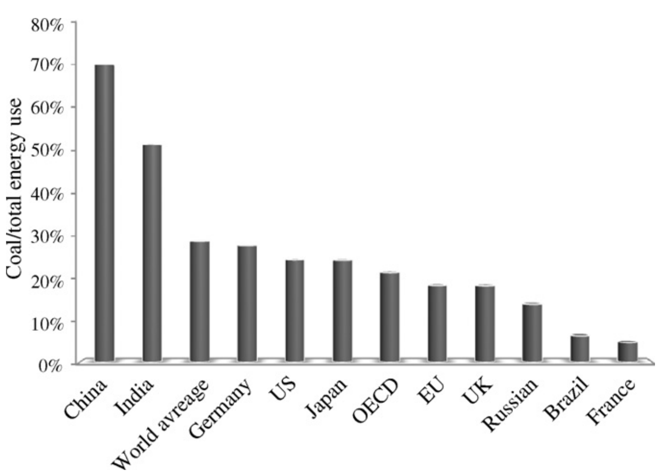

Fig. 3. Comparison of China's ratio of coal to total energy consumption in 2007 with selected countries and international organizations.*Source*: [16].

In addition, no industry depends on coal to the extent that electricity generation does in China (see Fig. 4). China's installed coal-fired electricity capacity was 554.42 GW, or 77% of the total installed capacity in 2007 [15]. In 2007, China's power output reached 3256 TWh [14], second only to the United States' nearly 4157 TWh [17]. Coal accounted for 83% of all power generated in 2007 [15], far above the world average of 40% (IEA, 2007).

If maintaining the rate of coal-fired power, China is projected to require 2.0 billion tons of power coal by 2020 [18]; a doubling of the 2007 production of 2.3 billion tons, half of which almost 50% is used power coal [15] (see Fig. 5). Already, China uses more coal than the United States, the European Union and Japan combined [16].

2.3. Operation and administration

China's current power industry operation and administration system have formed since 2002, when the landmark the *Scheme of the Reform for Power Industry* was enacted [19]. Before the reform, China's power sector was monopolized by the State Power Corporation, which held 46% of nation-wide installed capacity and 90% of transmission asset. Since the reform, the State Power Corporation was dismantled. Five independent electricity generating stations (China Huaneng, China Datang, China Huadian, Guodian Power, and China Power Investment) were established to share power generation asset of State Power, and two transmission companies (State Grid Corporation and South Power Grid) were set to share grid asset of State Power (see Fig. 6). At the same time, four consultant and construction companies were also split from State Power to make them more efficient. And a ministerial-level industry watchdog, the China Electricity Regulatory Commission

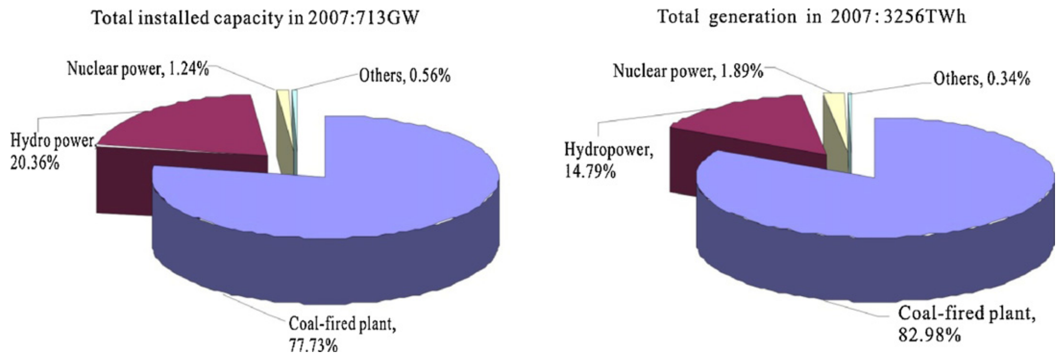

Fig. 4. China's fuel mix for power generation in 2007.*Source*: [14].

(SERC), was founded [20]. However, SERC is an ostensibly independent regulator. As of to date, summer 2009, the National Development and Reform Commission (NDRC) has refused to yield key tools to SERC, including the authority to determine prices and approve new capacity installations, preventing SERC from fulfilling its mission [21].

3. Hydropower

3.1. Hydro resources in China

China has many substantial rivers, more than 50,000 of which cover a basin area of over 100 km^2, and 3886 of which have a hydropower potential of over 10 MW (megawatt). According to the re-check results on the national hydropower resources survey, the theoretical potential of hydropower resources in China is 694 GW, annual power output 6080 TWh, technical exploitable capacity 542 GW, technical exploitable annual power output 2470 TWh, economic exploitable capacity 402 GW and economic exploitable annual power output 1750 TWh [22] (see Table 1).

However, the distribution of hydro resources is uneven. Southwest China which includes the four provinces Sichuan, Tibet, Yunnan, Guizhou and one city Chongqing has the most hydropower resources in this country, followed by Mid-South China, and lastly North China (see Fig. 7).

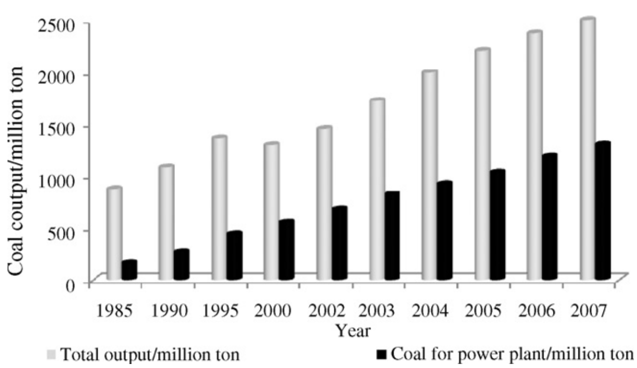

Fig. 5. Chinese coal output from 2000 to 2007.*Source*: [15].

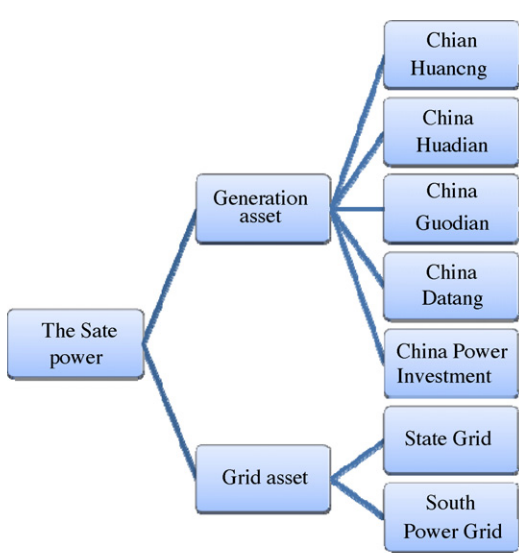

Fig. 6. The structure of the power assets in the Reform in 2002.

3.2. Status of hydropower in China

Currently, in the consumption of primary energy, the percentage of hydropower in China is 5 points lower than the world's average. And about 2/3 of the commercially usable hydro energy resources must still be developed [4].

By 2007, the installed capacity and energy generation of hydropower totaled 145.26 GW and 486.7 TWh, about 891 and 685 times that of 1949, with annual average growth rates of 12.4% and 11.9%, respectively. Volume doubling occurred in less than 7 years [23] (see Fig. 8). The share of hydropower in the total installed capacity rose from 8.8% in 1949 to 20.36% in 2007, while decreased from 16.5% to 14.95% in total electricity generation [24].

3.2.1. Giant hydropower

The construction of giant hydropower stations in China started in the 1950s, when a 108 m high gravity dam was built between April 1957 and September 1960 with Soviet consultation close by the city Sanmenxia, Henan Province. Since the 1980s, with the building of the Gezhouba Hydropower station, with an in place capacity of 27.1 GW, the construction of giant hydropower station entered a new rapid development phase [25]. Since the 1950s, almost half of the world's large dams have been built in China [26]. Among them, Three Gorges Dam is the biggest one. With a long history of planning and more than a decade of construction, the dam body was finished in 2006. When the whole project is completed, it will contain 32 main generators, each with a capacity of 700 MW [27].

China has planned to construct 13 hydropower bases according to the *Medium and Long-term Development Plan for Renewable Energy* (see Fig. 8). They are Jinshajing River, Yalongjiang River, Daduhe River, Wujiang River, the Yangtze River Up Reaches, Qingjiang River, Nanpanjiang River and Hongshuihe River, Lancangjiang River, the Yellow River Up Reaches, the Yellow River Main, West Hunan, Fujian and Zhejiang and Jiangxi, the Northeast and Nujiang River. If the hydropower resources in these bases are completely developed, the installed capacity will amount to 275.77 GW [28] Fig. 9.

Table 1
Hydropower potential in China.

Province/area	Theoretical potential		Technically exploitable hydropower potentials			Economically exploitable hydropower potentials		
	Annual energy output (TWh)	Average power (MW)	Number of hydropower stations	Installed capacity (MW)	Annual energy output (TWh)	Number of hydropower stations	Installed capacity (MW)	Annual energy output (TWh)
Southwest China								
Tibet	1763.9	201,358.2	338	110,004.4	575.9	191	8,350.4	37.6
Sichuan	1257.2	143,514.7	2146	120,040	612.2	1,855	103,270.7	523.3
Yunnan	914.4	104,386	796	101,939.1	491.8	751	97,950.4	471.2
Chongqing	201.2	22,964.3	421	9,808.4	44.6	323	8,195.9	37.8
Guizhou	158.4	18,086.4	601	19,487.9	77.8	474	18,980.7	75.2
Mid-south China								
Guangxi	154.5	17,641.2	826	18,913.8	80.9	764	18,575	79.5
Hubei	150.7	17,204.5	706	35,540.5	138.6	651	35,355.9	138.0
Hunan	116.3	13,270.4	969	12,020.9	48.6	771	11,349.8	45.8
Guangdong	53.2	6,068.5	1,051	5,401.4	19.8	970	4,878.8	17.8
Hainan	7.4	842.2	85	760.5	2.1	82	710.5	1.9
Northwest China								
Xinjiang	334.4	38,178.7	518	16,564.9	71.3	495	15,670.5	68.3
Qinghai	191.6	21,873.8	241	23,140.4	91.3	178	15,479.1	55.5
Gansu	130.4	14,887.3	321	10,625.4	44.4	205	9,009	37.0
Shannxi	111.8	12,768.9	349	6,623.8	22.2	318	6,501.6	21.7
Ningxia	18.4	2102.6	11	1,458.4	5.9	11	1,458.4	5.9
East China								
Fujian	94.1	10,742	1,035	9,979.7	35.3	1,031	9,697.7	34.5
Zhejiang	53.8	6,163.8	1,074	6,643.8	16.1	1,071	66,132	16.1
Jiangxi	42.6	4,858.1	533	5,162.9	17.1	448	4,161.9	13.8
Henan	41.2	4,706.6	217	2,880.6	9.7	140	2,726.4	9.1
Anhui	27.4	3,122	157	1,074	3	144	996	2.7
Shanghai-Jiangsu	15.22	1,738.1	22	57.9	0.2	14	22.4	0.1
Shandong	10.2	1,170.1	50	64.2	0.2	37	50.8	0.1
Northeast China								
Heilongjiang	66.4	7,582.2	177	8,161.9	23.8	122	7,226.9	21.2
Jilin	30.1	3,439.6	202	5,115.5	11.8	171	5,042.3	11.5
Liaoning	17.8	2,031	203	1,767.3	6.0	174	1,728.9	5.9
North China								
Inner Mongolia	50.9	5,812.2	113	2,624.5	7.3	92	2,567.3	7.2
Shanxi	49.4	5,634.8	176	4,020.4	12.1	156	3,973.8	11.9
Beijing-Tianjing-Hebei	19.9	2,274.6	179	1,751.3	3.712	105	1,252.5	2.5
Total	6082.9	694,395.8	13,314	541,640	2473.9	11,680	401,796.8	6057

Source: [22].
Notes: The data in the table is from the rivers with a theoretical potential of 10 MW and above, an installed capacity in one hydropower station is 0.5 MW and above in a single project, not including the data of Hongkong, Macao and Taiwan.

Many hydropower projects under construction are set new world-class standards. For example, Jinping Hydropower Project will have the highest double curvature arch dam (305 m), Shuibuya Hydropower Project the highest face rockfill dam (233 m), and Longtan Hydropower Project the highest rolled compacted concrete gravity dam (216 m), and so on [24].

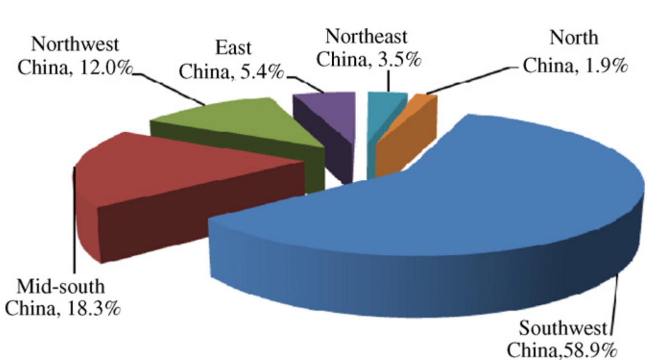

Fig. 7. The distribution of China's hydropower resources.*Source*: [23].

3.2.2. Small hydropower

Small hydropower in China refers to the hydropower generation with installed capacity of less than 5.0 MW (including 5.0 MW). The technological potential of small hydropower resources in China is 128 GW and a power generation is 450 TWh/year. It is widely distributed over more than 1600

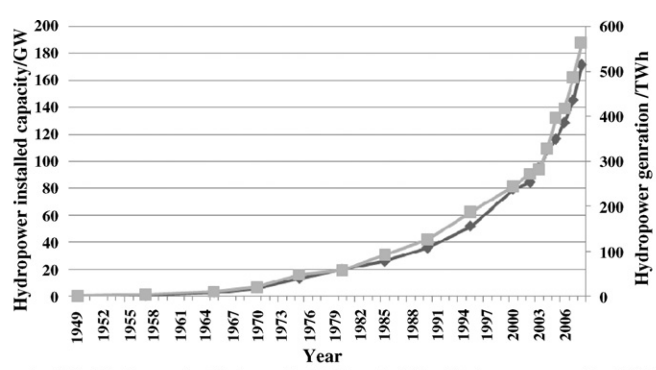

Fig. 8. Growth of hydropower in China during the past 58 years.*Source*: [24].

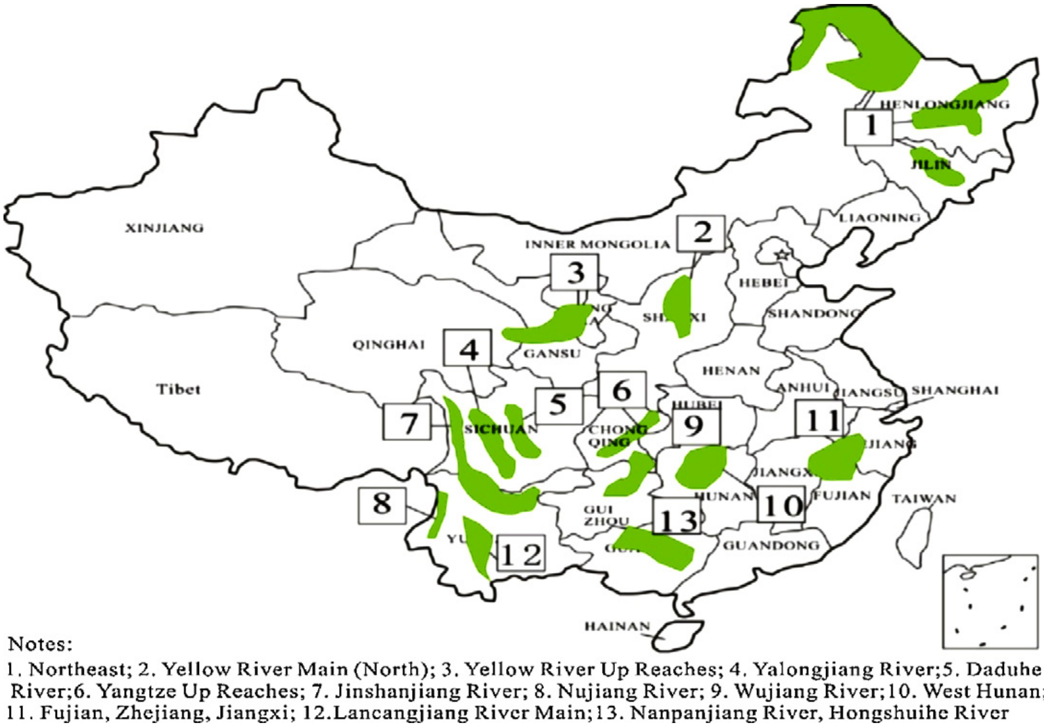

Fig. 9. Locations of 13 hydropower bases in China.*Source*: [28].

mountainous counties around the country. West China accounts for 67.6% of the total capacity, while for Central China and East China, the shares are 16.8% and 15.6%, respectively. By the end of 2008, small hydro projects had an installed capacity of 51 GW and an annual average generation of 160 TWh, which was about 30% of the total hydropower generation capacity in that year [29]. Currently, 15 small hydropower bases are under construction (Shaoguan and Qingyuan in Guangdong Province; Sanming, Longyan and Ningde in Fujian Province; Lishui in Zhejiang Province; Chenzhou in Hunan Province; Ganzhou in Jiangxi Province; Ya'an, A'ba and Liangshan in Sichua Province; Guilin in Guangxi Province; Shiyan, Enshi and Yichang in Hubei Province), each with an installed capacity of more than 1 GW [30].

3.3. Restrictive factors for hydropower development

The development of hydropower remains controversial. Concern arises largely from the public and centers on issues such as environment [31], security [32], and social impact [33] (see Fig. 10). Large hydro facilities, critics say, can flood important

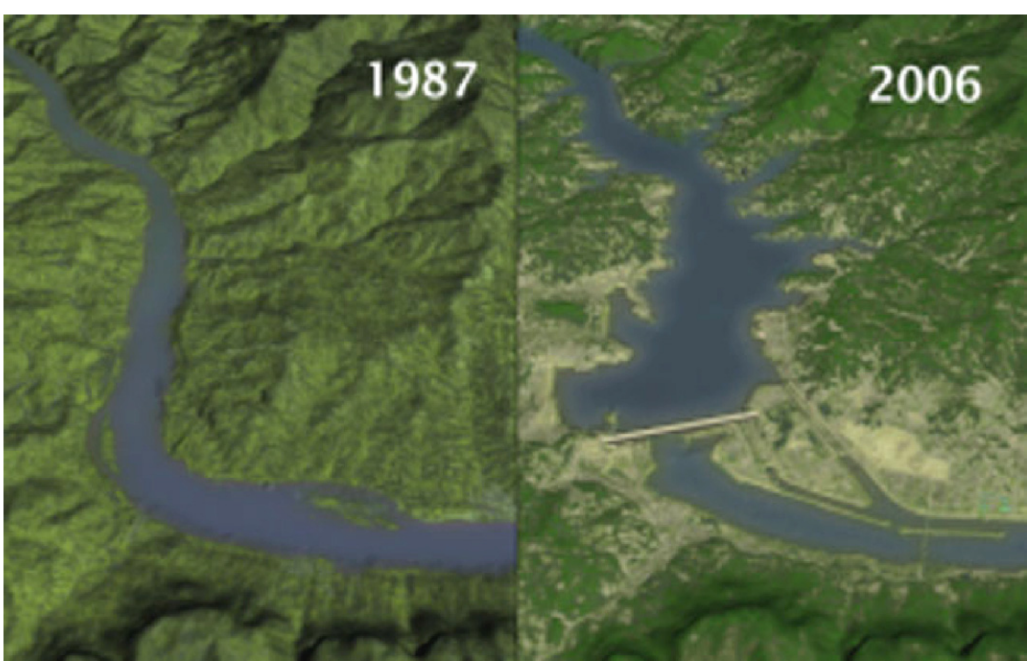

Fig. 10. Changed landscape of the Three Gorges Dam region.*Source*: NASA/Goddard Space Flight Center Scientific Visualization Studio http://www.our-energy.com/china_hydropower_as_the_right_solution.html.

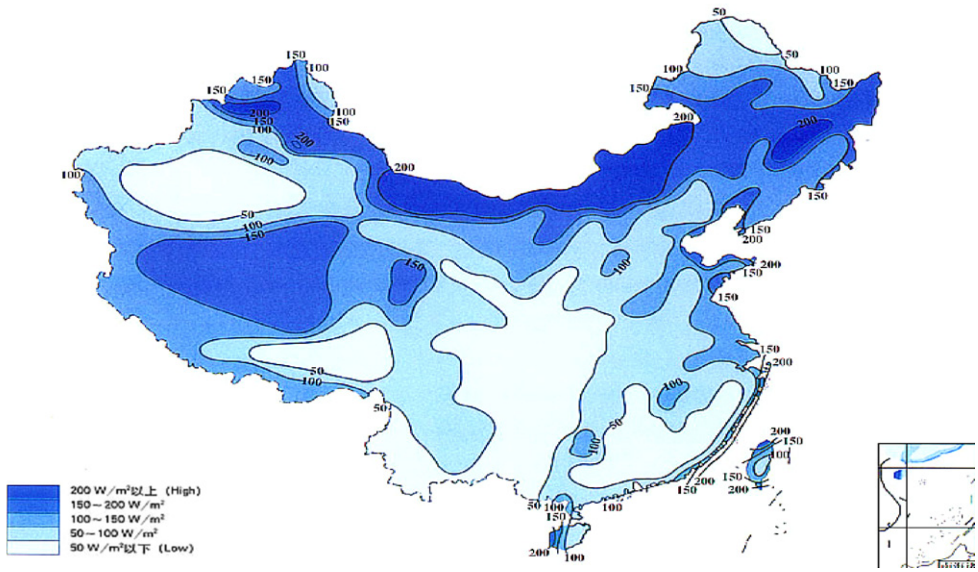

Fig. 11. Distribution of effective wind power density in 2008.*Source*: [35].

habitats, damage river ecosystems and surrounding flora and fauna, and destroy the livelihoods and cultural heritage of river peoples. Projects in problematic geological locations pose a high risk for disasters. Moreover, forced human displacement can lead to further impoverishment of socially vulnerable populations, rather than raising their standards of living.

3.4. Future prospect

China is well aware that hydropower is a renewable energy sector that can be used on a large scale within its borders. It is therefore making large investments in the future hydropower sector, although there are a lot of controversies. An additional 79 GW of hydropower will be installed during the Eleventh Five-year period (2006–2010), 68 GW of which will be from the large and middle-scale hydropower stations, and 12 GW from the small hydropower stations. By 2010, the total installed capacity of hydropower will reach 194 GW [30]. Moreover, the gross installed capacity of hydropower will reach 328 GW by 2020, 253 GW of which will be from the large and middle-scale hydropower, and 75 GW from small hydropower [28].

Of course, hydropower's impact on the ecological environment warrants close scrutiny, and should be analyzed and evaluated in a systematic manner before and during construction and operation of hydropower stations. Hydropower must be developed in line with ecological environment protection and in an orderly fashion to be fully utilizable.

4. Wind power

4.1. Wind resources in China

Throughout China's vast land mass and long coastline there is a rich resource of wind energy with great development potential (see Fig. 11). According to the last national investigation, the technically exploitable land area (with a wind power intensity of over 150 W/m^2) is approximately 200,000 km^2. Taking a ratio of 3–5 MW/km^2, the resulting exploitable wind power capacity would be 600–1000 GW. According to the *Report on Coastal Resources*, there is a further 157,000 km^2 of coastal areas around China with a water depth between 0 and 20 m. The installed capacity of offshore wind power could reach 100–200 GW if wind power can be realized at a density of 5 MW/km^2 over 10–20% of the sea. In summary, there is a huge wind power potential in China, of around 700–1200 GW [34].

4.2. Status of wind power in China

Grid-connected wind power started to develop in the 1980s, but grew rapidly in late years [36]. Up to the end of 2008, the accumulative total amount of installed capacity is 12.15 GW [37], China's wind power has experienced tremendous development since 2005, when the government enacted its landmark national *Renewable Energy Law*. Installed capacity grew by over 106% in 2006, 127% in 2007, and 105% in 2008, respectively [37–39] (see Fig. 12).

The geological distribution of wind power installed capacity is rather uneven. There are 12 provinces with installed capacity of more than 0.2 GW by the end of 2008. Inner Mongolia, with an installed capacity of 1.5 GW, ranks at the top. Following Inner Mongolia are Jilin, Liaoning and Hebei, with an installed capacity of more than 0.5 GW [37].

4.3. Barriers to development

Wind farms impact grid related power system operations unfavorably. This is an inherent consequence of the application of wind power but not attributable to an individual turbine. With the expansion of wind power and the increase of wind power ratio in a local grid, such unfavorable impact will likely become the technical bottle neck for wind power integration. Wind power decreases accuracy of load forecast and therefore affects power grid dispatching and operation. Moreover, wind power impacts frequency control of power grid, voltage regulation, power supply quality, fault level and stability of power grid [40].

4.4. Future prospect

Wind power is expected to be the country's third largest power resource after coal and hydroelectric power by 2020 [41]. In 2007, cumulative wind installations in China exceeded 5 GW, the goal originally set for 2010 by the *Medium- and Long-term Development Plan for Renewable Energy* [28]. So in 2008, policymakers had to double their wind power prediction (10 GW) for 2010. Still the total of installed capacity of wind power reached 12.15 GW by 2008 [37].

Six wind farm bases (Hami in Xinjiang, Jiuquan in Gansu, the eastern coastal area around Jiangsu, Inner Mongolia, the Zhangbei

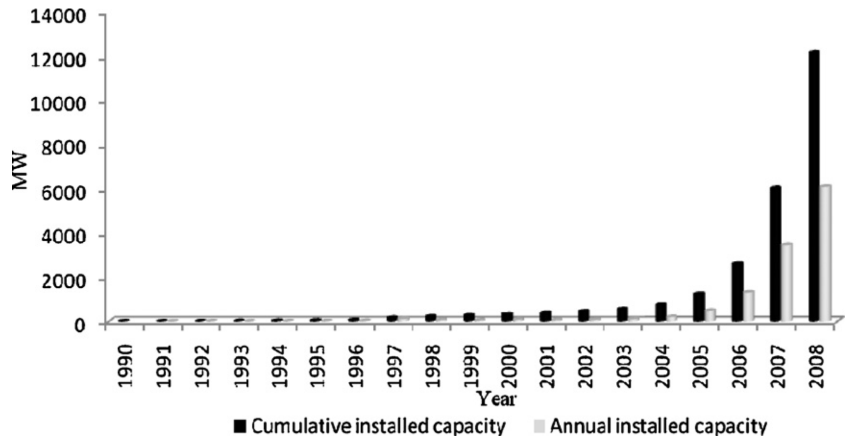

Fig. 12. The accumulative total of wind energy generating system in the past 19 years.*Source*: [36–38].

Region of Hebei, and Baicheng in Jilin) are under construction or planning each with a 10-GW level installed capacity. The planning of 10.65-GW wind power base in Jiuquan of Northwest China's Gansu Province has been completed and construction has started. Xinjiang plans to build a wind power generation base in the Hami area with a capacity of 20 GW. North China's Inner Mongolia aims to form a 20-GW and 30-GW wind power base in its Western and Eastern part, respectively. Plus, Hebei has proposed to set up a 10-GW wind power base in its coastal and northern area, and Jiangsu plans to build a 10-GW wind power base including 7 GW of capacity in the offshore area [42]. In addition, the biggest offshore wind power plant China is being built in Shanghai. Located north of the Donghai Bridge, the country's first long cross-sea span, the power plant will have an installed capacity of 100 MW [43]. It is projected that China's installed wind power capacity would see an increase of 100 GW by 2020 [42].

5. Solar energy

5.1. Solar energy resources in China

China lies in the northeastern part of East Asia between 4° and 53° North latitude and 73–135° East longitude covering an area of 9.6 million km^2. More than two-third of the country receives an annual radiation of more than 5000 MJ/m^2 and more than 2000 h of sunshine [35] (see Fig. 13). The areas with large amount of radiation include among others Tibet, Qinghai, Xinjiang, southern Inner Mongolia, Shanxi, northern Shaanxi, Hebei, Shandong, Liaoning, western Jilin, middle and southwestern Yunnan, south-eastern Guangdong, southeastern Fujian, eastern and western Hainan Island and southern western Taiwan. The Qinghai-Tibet Tableland, in particular, receives the most radiation.

5.2. Status of solar energy power in China

China began to research photovoltaic cells in 1958. In 1971, the PV cells were successfully applied in the satellite named "Dongfanghong II". However, the development was very slow before 2004. Since 2004, China's solar cell has experienced increasing growth, inspirited the booming of German PV market [44]. The total yield in China's solar cell in 2007 was 1088 MW, ranking it first in the world (see Fig. 14). Although China is a top manufacturer of solar panels, the high cost of the most efficient technologies hinders their deployment. By the end of 2007, the total installed capacity of photovoltaic power generation was

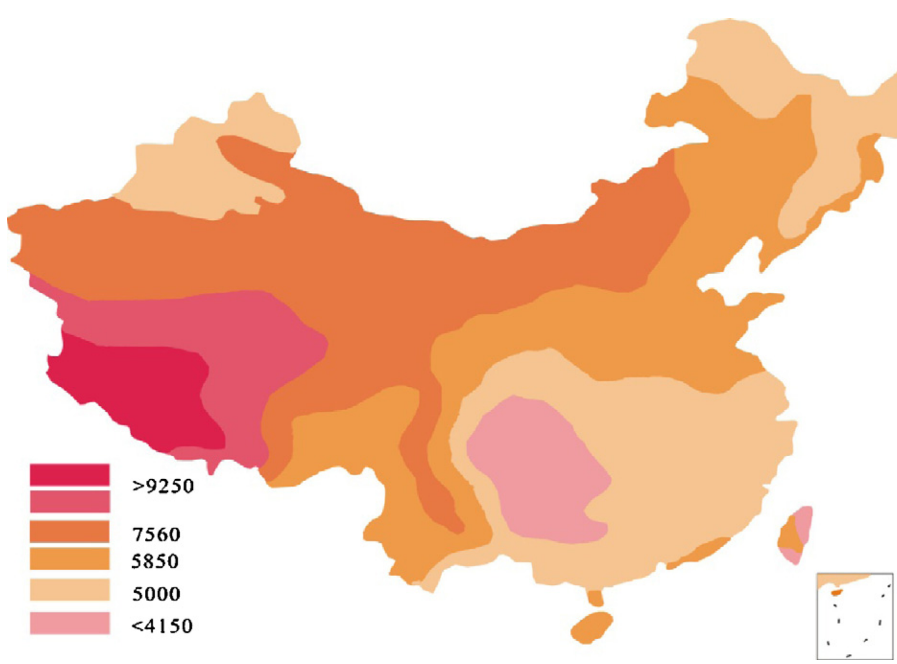

Fig. 13. The statistics of solar energy density in China (MJ/m^2 per year).*Source*: [35].

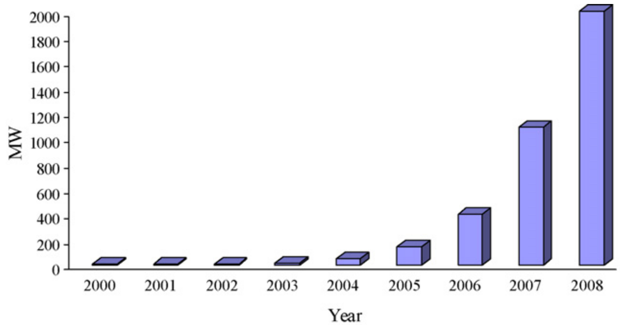

Fig. 14. The yield of solar cell in the past 8 years.*Source*: [44] and news.

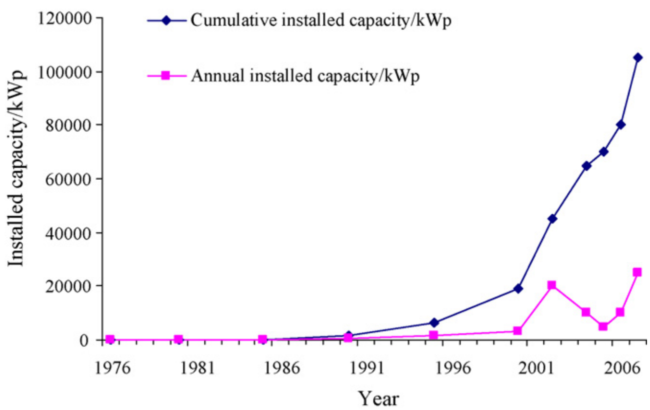

Fig. 15. The accumulative total of solar energy generating system in the past 30 years.*Source*: [44].

about 105 MW, and the new PV capacity 25 MW (see Fig. 15). At present, the small size and off-grid PV generation units are still main utilization form, i.e. solar-pumps and solar-light are being successfully operated in many remote villages lighting system, and many Western villages' electric power supply is implemented by using solar energy [45].

5.3. Barriers to development

The cost of PV power generation is the most and obvious barrier. In 2007, the average on-grid electricity price of PV power plants is RMB 4 Yuan (US Cent 58.9)/kWh [46], compared to the average on-grid electricity price of wind power RMB 0.617 Yuan (US Cent 9.1)/kWh, nuclear power RMB 0.436 Yuan (US Cent 6.4)/kWh, coal-fired plant RMB 0.346 Yuan (US Cent 5.0)/kWh, and hydropower RMB 0.244 Yuan (US Cent 3.6)/kWh [47]. It is difficult to enable solar power generation to advance on a large scale before the technological advancement substantially reduces the cost of PV power generation.

5.4. Future prospect

Photovoltaic generation is projected to be 300 MW by 2010 and 1.8 GW by 2020, respectively, according, to the *Medium- and Long-term Development Plan for Renewable Energy* [28]. However, this target is too conservative. The Chinese government has, in 2009, initiated 10 MW concession demonstration project in Dunhuang, Northwest China's Gansu Province. The Dunhuang project has reached a historically turn point to most Chinese PV makers. The prices disclosed were way below the perceived RMB 2 Yuan (US$ 0.29/kWh)/kWh as predicted. The highest price was offered by China Guangdong Nuclear Wind Power, at RMB 1.92/kWh Yuan (US$ 0.28/kWh), and the lowest by SDIC Huajing Power (600886.SH), and its bidding partner, NYSE-listed Yingli Green Energy, at RMB 0.69/kWh Yuan (US$ 0.10/kWh). Some criticize that such low price is harmful for the future healthy development of China's PV industry [48,49]. However, no one can deny the fact the solar power concession has effectively decreased the cost of PV power generation. In 2007, PV generation electricity was RMB 4 Yuan (US Cent 58.9)/KWh, and then in September 2008, Suntech Power Co., Ltd. China, Chinese biggest solar cell producers declared that it can reduce the PV power price to RMB 1 Yuan (US$ 0.15)/kWh by 2012, which inviting a hot applaud. However, in March 2009, the demonstration project has propelled the PV generation to reduce to the range of RMB 0.69 Yuan/kWh to 1.92 Yuan/kWh (US$ 0.16/kWh to 0.23/kWh). Solar energy concession project is seemed to drive the PV installed capacity rapidly grow in the future.

6. Biomass energy

6.1. Biomass energy resource in China

The employable biomass energy in China mainly includes crop stalks, firewood, manure, domestic garbage, industrial organic waste residue and wastewater. It is estimated that the total exploitable biomass energy in China is around 7×10^8 tce (ton of standard coal equivalent), about 3.5×10^8 tce of crop stalks accounting for more than 50%. Among the exploitable biomass energy resources, 40% of the crop stalks are used as feedstuff, fertilizers and industrial raw materials, and 60%, i.e. about 2.1×10^8 tce, are used for energy; firewood mainly used as fuel, but about 40% of the remnant forestry, i.e. about 0.3×10^8 tce, have not yet to be employed, a small proportion of human or animal manure is used as fertilizer, leaving the major part, i.e. about 0.6×10^8 tce, as the principal source of pollution in rural areas; at least 80% of the industrial organic waste residue is redeployed, i.e. 0.7×10^8 tce; and at least 0.8×10^8 tce is generated from domestic garbage. Consequently, China's theoretical biomass energy that could be used as energy could reach at least 4.5×10^8 tce [50].

6.2. Status of biomass generation in China

The employment of biomass energy in China includes biological chemical transformations (marsh gas and fuel alcohol), biomass gasification (power generation or thermal power co-production), biomass liquefaction (bio-diesel) and direct burning (boiler burning, dense burning and garbage burning). By the end of 2007, the installed capacity of biomass power in China reached 2.2 GW. Of this, the power capacity from bagasse was about 1.7 GW, with that from municipal solid waste incineration and land-fill gas power generation being about 400 MW. The rest of the afore-stated installed biomass power capacity was from gasification of agricultural or industrial wastes [51].

6.3. Barriers to development

The material has become the prominent barrier. In rural areas, the price of crop stalks has increased from 200 Yuan (US$ 29.4)/ton in 2007 to 310 Yuan (US$ 45.6)/ton in 2008. Moreover, the quality of crop stalks has decreased as farmer added water and even sand into the crop stalks to increase its weight so as to make more money. In city, municipal household waste sorted reclaiming has not achieved. The calorific value of municipal waste used as power plant's fuel is so low that it is not able to fuel the power generator unit with a good condition, sometime even can impair the boiler [51,52].

6.4. Future prospect

Biomass power includes power generation using biomass from agriculture and forestry/forest product wastes, municipal solid

Table 2
Operating uranium mines.

Mine	Province	Type	Nominal capacity tons U per year	Started
Fuzhou	Giangxi	Underground and open pit	300	1966
Chongyi	Giangxi	Underground and open pit	120	1979
Yining	Xinjiang	In situ leach (ISL)	200	1993
Lantian	Shaanxi	Underground	100	1993
Benxi	Liaoning	Underground	120	1996

Source: [53].

waste (MSW), and biogas. The priorities for biomass power development are as follows:

- *Straw stalk power generation*: The installed capacity will be 4 GW by 2010 and 24 GW by 2020, respectively.
- *Methane power generation*: Total installed capacity reach 1 GW by 2010 and 3 GW by 2020, respectively.
- *Waste incineration power generation*: By 2010, the installed capacity of power generation based on MSW will be 500 MW. By 2020, its installed capacity be 3 GW [28].

7. Nuclear power

7.1. Uranium resources in China

China's known uranium resources of 70,000 tons are theoretically sufficient to fill the short-term requirements for the mainland nuclear program. Production of some 840 ton/year – including that from heap leach operations at several mines in Xinjiang region (see Table 2) – supplies about half of the current needs. The remainder is imported (reportedly from Kazakhstan, Russia, and Namibia). Australian uranium will be imported starting late 2008. China's ores are low-grade and production has been inefficient judged by international standards [53].

7.2. Status of nuclear power in China

China's nuclear energy program has a relatively short history. In 1984, China National Nuclear Corporation (CNNC) began to construct its first indigenously designed and constructed nuclear power plant at Qinshan in Zhejiang Province, Southeast China. Meanwhile, severe shortage in Guangdong (a 1/3 gap between power production and demand) prompted a co-operative project in Daya Bay by China Guangdong Nuclear Power Holding Co., Ltd. (CGNPC). Since the first nuclear power plant went into commercial operation in 1991, China has completed 11 units at the end of 2007 in the coastal areas with their rapidly growing economy (see Table 3). As of 2007, there is 8.6 GW installed providing 62.86 TWh [53]. The slow development was not technology constrained, nor financial, or even by concerns for safety or waste disposal. Rather, it was due to the dominant thinking that given the amount of cheap coal in China there was no need to invest in expensive, technically difficult and politically sensitive nuclear power plants [54].

Rapid growth in electricity demand and power structure adjustment has prompted acceleration of China's nuclear power plants construction. China's government announced its intention to speed up nuclear energy development. The *Medium- and Long-term Nuclear Power Development Plan* was released in 2007. The government planned to increase nuclear generating capacity to 40 GW by 2020, with a further 18 GW nuclear being under construction. The total investment is projected to be RMB 450 billion Yuan (US$ 66 billion) [18]. The plan marks the transition of China's nuclear power industry from the original appropriate development into the accelerated development phase.

7.3. Barriers to development

Chinese ambitious nuclear power development plan will face the bottleneck of natural uranium fuel supply. To fuel its nuclear power installed capacity of 40 GW by 2020, China is projected to need 9814 tons [55] to 10,340 tons [56] of uranium by 2020. The cumulative demand is expected to reach 89,992 tons [55] to 91,364 tons [56] by 2020. However, the Chinese domestic natural uranium reserve is 31,800 tons (cost category to <US$ 40/kg), 44,300 tons (cost category to <80 US $/kg), and 48,800 tons (cost category to <130 US $/kg), respectively [57]. So the low cost proven uranium reserve (cost category to <130 US $/kg) in China only meets about half of that required to reach 40 GW generation capacity in 2020. It is evitable that China's must purchase a great quantity of natural uranium for its nuclear power plants.

Spent fuel management is a politically sensitive topic. Divisions among groups and public opinion can halt or stall a nuclear energy program, as has been seen in German. Yet, this only happens in democratic societies [54]. In China, governmental decree has virtually become the only decisive factor for spent fuel management. However, both central and local governments are currently focusing on the building of nuclear power plants, rather than on spent fuel management. In the *Medium- and Long-term Nuclear Power Development Plan*, the description of the spent fuel management warranted only two sentences. The local government is keen on nuclear power projects mainly because such projects drive the GDP growth. As a result, there are many unsolved problems in spent fuel management.

Another constraint may be a lack of skilled workers. Building and operating nuclear plants require a great many highly trained professionals, and enlarging this pool of talent enough to the rate at which new plants are brought online may prove to be very challenging.

7.4. Future prospect

In view of the enthusiasm shown for nuclear electricity throughout the country, the actual scale of Chinese nuclear power development is expected to exceed the present plan. In addition to upgrading long-term nuclear power development goals, a number

Table 3
Operating mainland nuclear power reactors.

Units	Province	Type	Net capacity (each)	Commercial operation	Operator
Daya Bay-1 and 2	Guangdong	PWR	944 MWe	1994	CGNPC
Qinshan-1	Zhejiang	PWR	279 MWe	April 1994	CNNC
Qinshan-2 and 3	Zhejiang	PWR	610 MWe	2002, 2004	CNNC
Lingao-1 and 2	Guangdong	PWR	935 MWe	2002, 2003	CGNPC
Qinshan-4 and 5	Zhejiang	PHWR	665 MWe	2002, 2003	CNNC
Tianwan-1 and 2	Jiangsu	PWR (VVER)	1000 MWe	2007	CNNC
Total (11)			8587 MWe		

Source: [18].

Fig. 16. Further nuclear power plants planned and proposed [51].

of inland, i.e. away from the coastal area, nuclear power plant projects are being planned, disrupting China's original nuclear power layout. The sitting of nuclear power plants will be not only Guangdong, Zhejiang, Shandong, Jiangsu, Liaoning, Fujian and other coastal areas, but also extended to the inland. At present, nuclear power projects are located in central China's Anhui, Hubei, Henan, Hunan and Jiangxi provinces, north China's Jilin, Hebei Province, southwest China's Sichuang Province, Chongqing City, and northwest China's Gansu Province are awaiting approval (see Fig. 16).

As a result, China may raise its total installed nuclear power generating capacity to over 70 GW by 2020, 75% higher than government target set in the *Medium- and Long-term Nuclear Power Development Plan* [58].

8. Other carbon-free energy resources

There are other carbon-free energy resources beside the above-mentioned in China, such as ocean energy and geothermal energy. Currently, the role of such resources is supplementary to other power.

8.1. Ocean energy

China's ocean energy resources include among others tidal energy, wave energy, oceanic flow energy, temperature difference energy, and salt difference energy. According to rough estimates, the theoretical reserve of China's tidal energy is up to 190 GW, the total installed capacity of developable resources around 20 GW and the average power generation is 620 GWh/a, among which 90% are distributed in Zhejiang and Fujian. The average theoretical reserve of wave energy resources is 12.9 GW, which are distributed in a rather uneven manner. The richest areas are Zhejiang, Guangdong, Fujian and coastal areas in Shandong [59]. The theoretical average power in oceanic flow resources is 139 GW. The resources are mostly distributed in Zhejiang, which accounts for more than 50% [60]. The theoretical reserve of ocean temperature difference energy resources is around $(1.19–1.33) \times 10^{19}$ KJ, the technically exploitable (heat efficiency at 7%) part is about $(8.33–9.31) \times 10^{17}$ KJ; the potential installed capacity of practically employable resources is 1320–1480 GW [61]. The reserve of salt difference energy resources is about 3.9×10^{15} KJ, with a theoretical power of 125 GW [50].

China's oceanic energy took its first step very late; currently, only tidal energy has reached maturity, leaving application of most other oceanic energy at the exploratory stage. The Chinese government expects the total capacity of tidal power generation to be 100 MW by 2020 [28].

8.2. Geothermal energy

Chinese geothermal energy is mainly located at the circum-Pacific tropical zone and Himalaya–Mediterranean tropical zone. More than 3200 geothermal spots have been found, with an annual naturally heat release of 1.04×10^{17} kJ, i.e. 3.56×10^{9} tce, 80% are being geothermal hot land below 100 °C. Geothermal power generations remain inadequate. The largest geothermal power station is located in Yanbajing, Tibet, with a capacity of 25.18 MW [62].

Table 4
Sketch information about China's carbon-free generation.

Type	Assessment resource	Status	Potential for future
Hydro resource	542 GW (technically exploitable reserves)	145.26 GW in 2007	328 GW by 2020
Wind power	700–1000 GW (theoretical reserves)	6 GW in 2007	100 GW by 2020
Nuclear power	48,800 tons (cost category to <130 US $/kg)	8.6 GW in 2007	>70 GW by 2020
Biomass	4.5×10^{8} tce	2 GW in 2007	30 GW by 2020
Solar energy	2/3 of the country receive an annual radiation of more than 5020 MJ/m^2 and more than 2000 h sunshine	105 MW in 2007	>1.8 GW by 2020

9. Conclusion

In all, China has plenty of free-carbon energy resources (see Table 4) to revolutionize its electricity structure and redirect it towards low-carbon electricity systems. Needed are the effective energy policies to get to the way. The boom in China's electricity is both a challenge and an opportunity. If China takes a series of effective and strong energy policies, the proportion of coal-fired power (80% of total electricity) to the total electricity will be decreased markedly. If on the other hand the government does not take substantial energy policies, it is projected to require 2.0 additional billion tons of coal, thus adding stress to a country that is already one of the biggest producers of carbon dioxide emissions in the world. However, we are confident that a low-carbon electricity system is achievable provided that effective energy pricing policies are adopted by China's policymakers. The outcome will affect not just China, but the entire world.

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